Art. VIII.—*Notes on Barometer Construction.*

By George Foord, F.C.S.

[Read 12th July, 1877.]

At the last ordinary meeting of the Society my name was on the list for reading an account of a proposed new form of barometer—a somewhat free translation of a paper appearing in a recent number of Poggendorff's *Annalen*—it being understood that papers possessing this degree of originality may from time to time be brought upon their own merits under the notice of the Society. For want of time the reading was postponed, since which postponement it has occurred to me that there were other proposed forms of barometer which it might be also interesting to consider; moreover, that a few hints concerning barometer tubes, and the precautions to be observed in selecting, preparing, and filling them—points which have fallen within the range of my own personal experience—might prove useful. Most of those who follow physical inquiries in the colony find the necessity of at times helping themselves, often to the extent of repairing, and occasionally of constructing, the instruments upon which their work depends; and therefore it is believed that an interchange of views and experience concerning minor details of construction—such as those now offered—may not be wholly devoid of interest.

I will then, with your concurrence, proceed in the first place to give a few hints calculated to assist those who may choose for the first time to try their skill in barometer building; and I will afterwards make reference to the forms of barometer proposed respectively by C. Bohn, by Guthrie, and an old proposition of Descartes incidentally mentioned in Mr. Guthrie's paper, and which is not dissimilar in principle to a form brought under the notice of our Society last session, and which originated with Mr. Venables.

First, then, as to the glass tube to be used. Its selection is a matter of primary importance. Callipers or gauges will enable us to ascertain how far the bore of a glass tube, otherwise applicable to our purpose, is of the same diameter at the two ends; for such gauges we may use very taper cones of copper or brass, or acute-angled plates of copper, brass, or zinc. Or we may choose to be more exact, and properly calibrate our tube throughout; although it must be here admitted that even for a syphon barometer it is only a few inches of each end of the tube which is required to be of uniform diameter. For calibration, if the interior diameter of the tube be small, say not exceeding two, or at the most three millimetres, we may pass a cylinder of mercury of known weight from end to end of the tube, accurately measuring the length of this thread of mercury progressively during its course; this will give data from which we may calculate the mean diameter of the bore of the tube in every portion of its length.*

For the calibration of wide tubes we may close one end, and, fixing the tube in a vertical position, weigh or accurately measure into it definite constant quantities of mercury. Or a method well calculated to avoid air bubbles may be practised by fitting the lower closed end of the tube with a glass reservoir, furnished with tubular terminations and glass or steel stopcocks. This reservoir with its tubes has the form of the letter U, the reservoir forming the thick arm of the letter (see Fig. 1). The parallel vertical tubular branch representing the thin arm contains a stopcock of supply, while a second stopcock for discharge of the mercury from the reservoir is placed at the lower portion or bend of the U. The whole requires to be fixed on a vertical board, and a funnel with capillary lower termination, of a length

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* For purposes for which it is convenient to gauge, with a metallic gauge, the interior diameter of the two ends of the glass tube, the calculation for the estimation of the relative diameter of the intermediate parts becomes very simple, as the following example chosen as affording a simple illustration will show :—Say diameter at each or either end is found by the gauge to be 4 millimetres, and that we introduce a cylinder of mercury measuring in this part of the tube 10 millimetres in length. Suppose that we pass this column along towards the centre of the tube to a position in which its length is exactly doubled, becoming 20 millimetres, the cubic measurement of the mercury is $4^2 : \cdot 7854 : 10$; but for our purpose, as the proportion ·7854 to unity is common to all the sectional areas we may discard this factor ·7854, and thus we deal with $4^2 : 10 = 160$. This in the portion of the tube where the length of the mercurial cylinder is doubled, occupying 20 millimetres, divided by the latter ($\frac{160}{20} = 8$) will give a quotient of 8, the square root of which, say 2·84 millimetres, is the diameter of the centre of this portion of the tube; and so indeed for any other part, the square root of the quotient obtained by dividing 160 by the length of the mercurial column in that part will give the local diameter. Of course in tubes selected for their apparently near approach to a perfectly cylindrical form the length of the mercurial calibrating column will be nearly uniform throughout, but whatever differences there may be are calculable from results obtained by the method described. See illustration A.

FIG I

greater than that of the barometer tube to be calibrated, must be used. Immediately under the bowl of this funnel is a stopcock which, when the point of this long funnel tube is lowered to the bottom of the barometer tube, enables us to regulate the supply of mercury, so that the surface of the fluid mercury rises slowly and equably, filling the tube without locking in a single bubble of air against the inner glass surface of the barometer tube. The glass measure fitted to the lower end of the barometer tube, as already described, is a spheroid with tubular ends. There is a narrow vertical glass tube forming its upper opening, and on this narrow glass tube a measuring mark is made; a second mark is also placed on the tube below the lower orifice of the bulb. With this arrangemeut we can calibrate the barometer tube. We first fill the tube under trial with mercury; we then open the stopcock of supply and allow mercury to run off until it has reached the trait x below the bulb. We now mark on the barometer tube the position of the upper surface of its mercurial column. We next open the stopcock of supply, until we have filled the measuring bulb to its upper mark y, when we mark the level to which the upper surface of the mercury has descended in the barometer tube. The supply cock being shut off, we next open the discharge cock, allowing mercury to flow slowly out until the lower mark is reached. In this way the measuring bulb is slowly and accurately alternately filled and emptied between the two gauge marks, and after each filling the level of the mercury in the barometer tube is carefully registered on it. This is continued until the barometer tube is almost or quite emptied, by which time we have marked it with subdivisions throughout its length, each of which we know to be of capacity equal to the rest, and from their several distances apart the diameter of every portion of the tube can be computed. The temperature of the mercury and the weight of the bulb measure of mercury should be noted, and when extreme accuracy is the aim there are other influences to consider and allow for; but the *modus operandi* is essentially what I have described whenever a barometer tube, or indeed a straight glass tube of any kind, is to be calibrated. The data for correcting the bulk of the mercury for temperature, &c., &c., are fully set forth in physical treatises, and therefore I need not further allude to them in this place.

If we consider the mode of manufacture of these glass barometer tubes we shall easily understand their liability to the conical as distinguished from the cylindrical form. A hollow stout cylinder of soft semi-molten glass is formed on the end of the blowing tube, and a second heated blowing tube is attached to the outer end of the ductile mass. The two workmen, each holding one of these blowing irons, retreat from each other until the glass tube is drawn down to the requisite diameter, say until they are twenty or thirty feet or more apart. A ladder of suitable length has been laid on the floor, and on this the glass tube is now laid and detached from the blowing rods at each end. It is eventually cut into six-feet or three-feet lengths, in which state the tube is ready for removal to the annealing lear (if it be annealed at all). The "butts," that is to say, the two outer lengths which were in immediate contact with the blowing irons, are sensibly conical, and the other segments of the entire tube are liable in degree, according to their position, to this conicity, and therefore it is a point of primary importance to gauge the tubes during selection in the manner already described, so as to obtain pieces which are sensibly cylindrical.

There are certain other points in selecting the glass tubes which will require attention—clearness of the glass, freedom from knots, and similar defects, &c.; but these are too obvious to require further mention.

As barometer tubes are required in most cases to be of stout glass, it therefore becomes necessary that they should have been effectually annealed; and here enters into the consideration a curious point of interest. I think I need not hesitate to say that much of the glass tube met with in commerce is either imperfectly annealed, or, as in the case of tubes with thin walls, it has not been annealed at all. The question of the degree of annealing which each kind of tube requires is regarded I believe in a purely commercial spirit; providing what will sell, and especially regarding the consideration of cheapness of production. As there is more in this statement than might catch our attention, I ask your patience while I go into the question a little more fully. Unannealed glass is glass in a condition of strain or unequal tension, and that portion of it which is unduly stretched is liable, on slight prompting, to rupture; such glass will not bear sudden vicissitudes of temperature, or sudden mechanical shocks, or the slightest scratch upon its strained inner surface. But glass may be in a condition of high tension and may at the same time possess very marked properties of permanence. If we optically examine vessels of De la Bastie's toughened glass we find them showing in a beam of polarised light the black cross indicative of strain, and we know that these specimens of glass will resist mechanical shocks of great violence, and that they have some other marked properties conducive to permanence; but if sufficient external force for the fracture of one of these vessels be employed, it does not simply break as annealed glass would break, but goes off with a report and is shattered throughout into a complete ruin of small particles. The "Bologna vial" and the "Prince Rupert's drop"* are each permanent in this sense, and each under proper conditions liable to disruption; and, in fact, we have to distinguish between irregular and symmetrical strain in order to gain a clear insight into the question of fracture of glass tubes, especially fracture due to imperfect annealing. Just as the Bologna vial is safe as long as you hammer its external surface, but flies into fragments as soon as you scratch ever so slightly its strained interior surface, which has cooled and contracted after the exterior layers have become solid, so a large proportion of the glass tubes found in commerce are permanent enough as long as we do not suddenly heat them, and so long as we do not bring hard substances in contact with their inner surfaces. Experience has taught the glass manufacturer that, unlike pieces of complex form, thick glass tubes with little annealing, and thin glass tubes with none at all, or next to none, are sufficiently permanent to serve most of the purposes of commerce. Take a stout glass barometer tube and pass through it an iron wire so as to rub the inner walls of the tube with the latter, the chances are great that after this treatment the tube will very soon crack; indeed it is unsafe to touch the interior surfaces of stout glass tubes with iron at all, as no instrument made with tube thus treated will be afterwards reliable. Regard the inner surfaces of your glass tubes as possessing in degree the physical properties of the inner surface of the Bologna

* The latter are called by the French "Larmes Bataviqne;" concerning the properties of which bodies the reader is referred to an interesting memoir by M. Victor De Luynes in the *Annales de Chemie et de Physique*, 3rd series, Vol. XXX. p. 289.

vial, treat these surfaces accordingly, and you will thereby effect much towards the permanence of whatever instruments you form from glass tubes.

But there are two kinds of glass (chemically speaking) of which barometer tubes are made; these may be distinguished in general terms as "crown glass" and "flint glass"—I might say Continental glass and English glass, as "crown" glass tubes prevail, as a manufacture, on the continent of Europe, while most of the English glass tube is of the "flint" variety. Besides the silicic acid and alkali the crown glass contains a basis of lime, which is replaced in the flint glass by lead oxide, so that "lime glass" and "lead glass" are equally distinctive terms. The lead glass is soft, the lime glass is hard; the lead glass is easily fusible, the lime glass is less easily fusible; the lead glass has less cohesive strength than the lime glass, as may be easily seen by trying the breaking weights of rods or tubes (of equal stoutness) of these two qualities of glass.* Lead glass is more pellucid than lime glass; tubes of the latter being mostly striated throughout by lines which in reality are air bubbles drawn into cylindrical cavities or threads of extreme tenuity. Although the strength of lime glass may recommend it for the construction of barometers to be used in the field, on the other hand lead glass offers advantages for instruments intended for indoor or laboratory use. The lead glass is easier worked, is sufficiently strong for use in careful hands, and in this material tubes free from defects and of beautiful uniform transparency can be easily obtained.

Whatever the pattern of the barometer, the tube from which it is to be made must be first examined as to equality

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**Experiment on cohesive strength of lead and lime glass tubes*:—

Relative weights of the glass tubes—	
A, lead glass	1123 grains
B, lime „	836 „
Length of the tubes...	each 15 inches
Bearing (wood) edges	10 inches apart
Exterior diameter of each tube	very nearly ½ inch
Breaking weight of A	32½ lbs. avoir.
„ „ B	46 „ „
Specific gravity of A	3·27
„ „ B	2·509

The tubes were gauged and selected so as to be as nearly as possible of the same exterior diameter and diameter of bore; the breaking weight was gradually increased by progressive addition of lead bullets to a tared suspended scale until fracture ensued.

of bore, and the exact diameter of the bore is also to be ascertained, because when the tube is closed and filled, and especially when bent into the syphon form, the ascertaining of these points is no longer readily accomplished. The tubes chosen for making into barometers will be often longer than is requisite for the instrument, and the end cut off may be almost or quite the same diameter as the upper end of the barometer; when this is the case it may be worth while to carefully label and set aside this end piece, which would at any time answer any question concerning the curve of the meniscus or any of a kindred nature which might arise. Concerning capillarity, a suggestion may be offered:—With any tube about to be employed, or with the end piece of tube cut off as just mentioned, a measurement of the effect of capillarity may be made by a method given in Bunsen's Gasometry:—Measure a column of mercury in the tube *per se*, and measure the same column after covering it with a few drops of corrosive sublimate solution: in the former case you have the meniscus proper to the given diameter of tube in its integrity; in the latter the mercury assumes a horizontal upper surface, and the difference of height of the two columns is that due to those physical causes which are collectively spoken of as the influence of capillarity.

Before proceeding to clean the inner surface of the tube it will be well to become acquainted with what has been ascertained concerning chemically clean glass, as especially set forth in the papers of Tomlinson.* In the *Chemical*

* When you have prepared with all precautions your supply of mercury for the cistern and for filling the tube, I will suppose in a clean porcelain vessel, with a nicely-polished glass bell jar for a cover, in a relatively dust-free apartment, you may try a simple experiment which is suggestive of the necessity of extreme cleanliness in barometer construction. Let the experimenter elaborately wash his hands, and then press his finger against the pure mirror surface of the mercury; he will, if I am correct, produce a minute and faithful oleograph of the skin structure—a picture of the skin surface—drawn in sebaceous and epithelial particles, which the cuticle, however well cleansed, is always ready to throw off. Now if you take up Deschanel's *Manual of Physics*, or other elementary work of the kind, in which the barometer is figured and described, you will see a wood engraving of the Torricellian experiment:—the hand inverting the tube filled with mercury, and the finger about to be placed on the open end on the mercurial column, before its insertion in the cistern—all very good for lecture table demonstration, but certainly violating the rules according to which a good barometer should be filled and erected. You cannot blow through a tube or touch the end of it without making a fouled surface; and although I am not prepared with any suggestions for the best method of meeting this

Dictionary of Watts, article "Barometer," will be found an account of the formation of the large bore barometer of the Kew Observatory; it will there be seen that the tube was polished out with alcohol and whiting (precipitated chalk, probably). Fuming nitric acid is an efficient oxident of greasy substances, and immersion of tubes in this acid before the final polishing, or first in oil of vitriol and next in nitric acid, would conduce to a satisfactory result; but whatever be done in the way of polishing out the tube, extreme care in avoiding the slightest scratch or abrasion of the inner glass surface must be observed. If iron wire be used for carrying the polishing plug, the wire must be covered completely with lamp cotton; the latter should have been previously purified by digestion in ether or bisulphide of carbon. But even with these precautions there is a risk of filaments, and perhaps, on the whole, it is best to avoid covered wire altogether. Brass or copper wire are less dangerous, but whalebone, or cane, or soft non-resinous or de-resinated woods have some peculiar recommendations.

I here may point out in reference to the cleaning of glass tubes generally, and especially to the cleaning of curved tubes with complex bends, and when whalebone of sufficient length is obtainable, that it possesses a property which cannot be too pointedly indicated to those who have not hitherto recognised it, and who are engaged in experimental physics. By its means some problems in cleaning the interior of complex forms of glass vessels can be solved which, to the best of my knowledge, are soluble by no other known means. A rod of whalebone is taken and shaped to our requirement; we intend to pass it through certain tubular crooked ways to reach a certain point on some remote inner surface; the material is elastic enough to pass through the tortuous duct, but when this is accomplished we have little or no control over the inner end of the slight constrained whalebone rod on which we depend for doing the work. But the possibility of doing

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requirement, it is still important to point out the difference between modes quite effective for lecture table demonstration, and those to be observed in the construction of instruments intended to meet all the requirements of precise physical research. Indiarubber finger stalls, collodion films, gutta-percha moulded valves, and similar contrivances, suggest themselves; but without attaching weight or preference to any of these, it still remains as a fact worthy of our best attention, that we cannot bring the hand into contact with pure mercury or chemically pure glass without in some measure fouling their surfaces.

the work resides, as I shall show, in the material nevertheless. If we carefully warm it over a spirit lamp we can bend it into curves corresponding with those of the crooked tube through which it is to pass, and when each of these bends has cooled we find that the whalebone rod has acquired a permanent set. We thus model an instrument whose axis is coincident with that of the crooked tube, and the elasticity and pliability of the rod remains. It gives and recovers itself as we humour it through the channels, and when we have put it in position it is free to be moved to a limited but mostly sufficient extent, so as to exercise the desired friction at the proper place, detaching a minute insect or a speck of dirt or mould, as the case may be. Doubtless this bending property of whalebone may be utilised in the hands of the physicist and chemist in other ways. Of course wood may be bent by heating or steaming, as instanced in boat-building, and in the familiar instance of walking-stick handles; but in the case of whalebone we have at the same time the permanent set and the elasticity of the material—a very valuable combination.

Concerning the use of cane rods for cleaning the interior of glass tubes, a suggestion may also be made. The elasticity of the ligneous material and its even cylindrical form recommend the cane for this purpose, but its siliceous glaze is obviously a dangerous element; this glaze can be readily removed by scraping with a knife, and cane rods thus stripped will be found sufficiently elastic, strong, clean, and safe for purposes of the nature considered.

For converting the tube open at both ends into the closed, and when required into the bent and shaped barometer tube, the enameller's blow pipe is used. I shall not enter into details on this point of the construction, as it is a matter of personal education and skill, and general directions of more or less value are to be found in technical works; but it will suit the limits of this sketch if the essential requirements of this class of operations are concisely stated. In closing, joining, or bending glass tubes they must be gradually heated to the required temperatures; the thicker the substance of the glass, or the less perfectly it is annealed, the more care will be required in gradually and equably raising its temperature. In closing the ends of tubes a little blowing for producing a hemispherical termination is mostly necessary. Remember that if this be done with the lungs the expired gases are charged with organic contaminations; a purely mechanical air pressure, as that supplied by a compressed indiarubber ball or condensing syringe, is free from this objection.

If sealed junctions are necessary for the construction of the barometer, these are not satisfactorily effected by pressing merely softened glass surfaces together; the glass tube ends to be joined must be well melted in the flame, then joined, and the joint must be retained in the molten condition in the flame until the whole of the softened portion has become identified into one homogeneous mass. Attention to the necessity of annealing such work as far as practicable will influence its durability. The air-driven gas flame used should, when lead glass is the subject in hand, be sufficiently oxygenated to prevent reduction of lead oxide to the metallic state and consequent blackening of the tube. One final remark, especially addressed to beginners in the work, is the advice to mark out in pencil on a smooth pine board the dimensions of the piece to be made at the lamp; this outline is used as a gauge with which to try the dimensions and angles of the piece, by juxtaposition, as it proceeds.

So much concerning the glass tube, whether for cistern or syphon barometer. Let us in the next place pay a few minutes' attention to the mercury. The mercury must be pure and dry, and free from all superficially adherent particles. When we allow a beam of sunlight to fall through a shutter hole into an otherwise dark apartment, we see that the air is permeated throughout with minute floating solid particles—motes which gyrate and eddy with every motion of the air, and which gravitate so slowly that in very few positions indeed is the air free from them. Among these particles are the germs which insinuate themselves between the lenses of telescopes, start into vegetative life, and feed on the glass surfaces, deadening them, just as the familiar lichen establishes itself upon and assists the decay of the hard surfaces of igneous rocks. I refer to these bodies with the object of calling your attention to the great necessity of employing the utmost care in the construction of glass instruments of the nature of the barometer, and the great difficulty of effecting absolute cleanliness of the glass inner surfaces, and the mercury to be employed, even when very great precautions are taken. Fortunately it is not difficult to ascertain when mercury is sufficiently chemically pure and mechanically clean, and fortunately very much of the mercury of commerce is found in a state of almost or quite chemical purity. Moreover it is fortunate that if the mercury to be employed contains lead, tin, or other such chemical impurity, it is a matter of no great difficulty to completely separate these metals. In the chemical handbooks you will find directions for several methods of treatment in the wet way; and you will find not infrequently an objection raised against purification by distillation, but nevertheless I venture to state that with all ordinary samples of mercury the method of distillation will be found easy and simple. Should the mercury contain traces of gold and silver—no infrequent occurrence in Victoria—in that case the humid methods described in the books would fail to remove these metals, distillation being the only effective mode of doing so.

First, it is easy to ascertain the purity of a sample of mercury. You warm and dry it very thoroughly; then you fold a piece of clean dry writing paper into a cone, having an exceedingly fine opening at the apex. The warm mercury is poured into this cone, and allowed to run out at the fine aperture in a very thin thread or stream, and collected in a perfectly clean white porcelain basin; any fine particles of dirt will adhere to the paper, and are thus removed, and the mercury collected in the basin, if pure or nearly so, will present a perfect mirror surface. But this brilliancy is not of itself a sufficient index of absolute freedom from base metals. Take half an ounce or less of this mechanically cleaned and warm mercury, and cause it to gyrate in a porcelain dish, also clean and warm; the metal is mobile enough, and a slight shake of the hand will make it circulate freely, when one of two results will happen—the dish will remain unsoiled, the mercury preserving always the spheroidal form and its perfect brilliancy, a certain indication of its freedom from base metallic impurities; on the other hand, if there are present the slightest traces of lead, tin, &c., the mercury will form a "talus" or queue, with tarnished surface, and will leave a stain or streak where it has passed over the glazed porcelain surface.

I notice in certain books a statement about the oxidation of mercury at common temperatures, which appears to demand a remark in this place. With impure mercury there is doubtless, even at common temperatures, oxidation—

oxidation of the metal forming the impurity; and this oxidation will be attended with the fouling and breaking up of the mirror surface by the formation of minute globules of mercury—a grey mass which the adventitious oxide prevents aggregating once again into the mirror form. But I think it may be correctly stated of pure mercury that, although it may be converted into red oxide at a comparatively high temperature, at ordinary temperatures of the atmosphere it undergoes no perceptible oxidation of any kind. Henry Watts* reiterates Gmelin's statement that "mercury remains unaltered when agitated for any length of time with oxygen gas, common air, hydrogen, nitrogen, nitrous oxide, nitric oxide, carbonic acid gas, or alcohol;" and I believe that statement is strictly true as applied to pure mercury and the ordinary constituents of atmospheric air.

If the mercury is found to be impure by the tests already given, or if it leaves the slightest residue—say of gold or silver—after evaporation of a small sample, it may be distilled. A cast-iron retort, with wrought iron exit-tube, is used for the purpose. It is furnished with a lid or cover with turned joint, and fastened with screw-bolts or key-wedges; a lute of moist clay secures the joint. The lid of the retort may be furnished with a stopper, which permits renewal from time to time of the charge of mercury without breaking the luted joint. The temperature at which the metal "boils," or is said to boil, is rather high, say 662° Fahr. or 350° C.; but the capacity for heat of the vapour of mercury, as compared with that of aqueous vapour for example, is so low that a small quantity of fuel will do a large amount of distillatory work, and the distillation is therefore rapid. Among the papers of the Royal Society of London, in the *Proceedings* of that body, and probably also in its *Transactions*, is a valuable contribution by W. R. Grove on the "Phenomena of Ebullition," in which it is shown how great an influence the gases dissolved in water exert upon the phenomenon. Water deprived of air can be converted into vapour, but in a manner which it would be incorrect to call boiling. As we apply heat, its temperature gradually increases, and eventually mounts beyond the ordinary boiling temperature; finally the super-heated water is in part converted into vapour by a sudden explosive act,

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* *Dictionary of Chemistry*, article "Mercury."

very different to what we call boiling. Now, oil of vitriol, methylic alcohol, and mercury—most probably on account of the absence of dissolved gases—are each converted into vapour with more or less tendency to sudden bursts and "bumpings," as they are called, and in these cases the distillates are liable to contamination with portions of the fluid, scattered and thrown over rather than distilled; and some kind of artifice is requisite in all such cases for obviating this source of an imperfect result. Many years ago a French chemist (M. Violette) recommended the use of super-heated steam for the distillation of mercury—a promising suggestion enough; but a purification completely satisfactory may be effected by simpler means. Three or four circular discs of iron wire gauze are allowed to float on the mercury in the retort, covering its whole surface; or, what is better, a layer of three-quarters of an inch of small cut or wrought iron brads are allowed to float on the metal; either of these forms a mechanical barrier, holding back the mechanically dispersed fluid mercury, but allowing sufficiently free escape for the mercurial vapour. For the reason already given a very small stream only of cold water, running over a cloth laid over the exit-tube of the iron retort, is requisite for re-condensation of the mercury. The lower end of the exit-tube is also bound round with a few folds of calico, which, projecting beyond it, form a tubular conduit, sufficient for confining and conducting the condensed mercury into a pan of water, and at the same time sufficiently pervious to the atmospheric air to prevent the water in the collecting pan being drawn up into the retort as a result of condensation of mercurial vapour at the end of the operation. I believe that a more extensive acquaintance with the efficacy of this simple method of distillation would cause its employment in preference to the several methods of chemical treatment.

A few observations on boiling out and other modes of filling glass tubes with mercury may now be added. Boiling out means raising the mercury to the temperature at which it freely forms metallic vapour, and so expelling the atmospheric air from the tube; it also means raising the mercury to a temperature at which its oxidation takes place when in contact with atmospheric air. The warm mercury is added in small doses to the inverted tube, and the boiling is brought about by heating the tube at a point a little below the mercurial surface; the boiling out thus proceeds from the closed end to within an inch of the open end of the tube. The tube is now filled up with hot mercury, and eventually it is suitably closed and inverted in its cistern of boiled pure mercury. To what extent or how syphon barometers are boiled out I am unable to state. Barometer tubes may be boiled out or filled with warm mercury without boiling out. The great standard barometer of Kew Observatory, which has a bore of one and one-tenth inches, was filled by the aid of the air-pump, and without boiling out. The Torricellian void above the mercurial column is stated to have been, when the instrument was completed, quite air free. I venture to express an opinion that the boiling out of barometer tubes is a mistake. The formation of oxide of mercury may not be grossly palpable; but I fear it is hardly possible to avoid the formation of some oxide, and that the quantity, however small, may have its effect upon the sensitiveness of the instrument. Possibly the intervention of microscopic crystals of red oxide of mercury between the metal and the glass may ultimately favour the entrance of air into the void. The mode in which mercury distils, and the absence of specific knowledge concerning any power which mercury may possess of absorbing or occluding gases, would appear to suggest that as far as the mercury itself is concerned the boiling out is unnecessary; or, if necessary for depriving the mercury of air, or gas, or vapour, of any kind occluded in its substance, as on that account ineffectual, for if the metal has this property it must soon again take up what we have expelled at the exposed surface in the cistern, and when saturated eliminate them into the void, while all our experience of the comparative permanence of the Torricellian vacuum renders this supposed property of mercury improbable, the small and slow creeping in of air being quite in unison with the fact of there being no real adhesive contact between the metallic column and the glass tube. Moreover, glass tubes, especially those of complex form, are jeopardised by the boiling process. A carefully and fortunately selected tube, well prepared, and therefore valuable far beyond its money cost, may be broken during the boiling by the turbulent and sudden bursts of mercurial vapour; or, if not actually broken during the boiling, it may be reduced to such a state of molecular unrest as to break with apparent spontaneity, some time after it is finished and mounted, or on receiving some slight concussion. We should also remember, as pertinent to this question, that it is not only losing the materials and the outlay of valuable time expended on the construction of the instrument itself, but by the loss of such an instrument after it has been brought into use, a break in the continuity of our results is brought about, and we resume observations with a new instrument, whose index, error, or deviation is different. It would seem that with the Sprengel-pump and other modern appliances at command for obtaining voids as good as have been hitherto by any means obtained, boiling out has become unnecessary and undesirable.

Concerning the mounting of barometers and the mechanical means for dividing the brass or other scales, I may state that these are beyond the scope of the present notes; but to those who essay to construct for their own use this instrument, I may mention one form of mounting which offers the advantage of simplicity in the materials of construction, enlisting glass and mercury only for the tube and its scale, and therefore to that extent simplifying corrections of the reading. On the mercurial tube mounted on a board and dipping into a glass cistern there is fitted an outer glass tube; the latter is divided, forming a scale which reckons from a glass rod fixed on to the lower end of this outer tube. This outer tube can be raised or lowered by a light cord or wire passing over a small pulley, and attached to a winch of glass rod working in a cork socket near the mercurial cistern. Before an observation is made this tube is raised or lowered until its zero pointer coincides with the mercurial surface in the cistern. The temperature is then taken; the reading made and the correction of the column for temperature concerns merely the expansibility of mercury and glass. There is a drawing of this arrangement attached to a Sprengel pump in the illustration to Mr. Mica Smith's paper on "The Motion of Bodies under the Influence of Radiant Energy" in a recent volume of our *Transactions.*

This completes what I have to communicate respecting the selection and preparation of barometer tubes and the mode of filling them, and I will therefore now proceed to the description of three several proposed forms of the instrument, each of which possesses features of interest, and perhaps I may correctly also state that each appears to be not wholly free from structural defects. First, that proposed by C. Bohn is described in Poggendorff's *Annalen* 1877, first part, p. 111, the paper being entitled "On the Construction of an Air-free Barometer, quickly, easily, inexpensively, and without boiling out:"—

"The syphon barometer has well-recognised advantages over the cistern barometer, but it possesses also its own particular disadvantages.

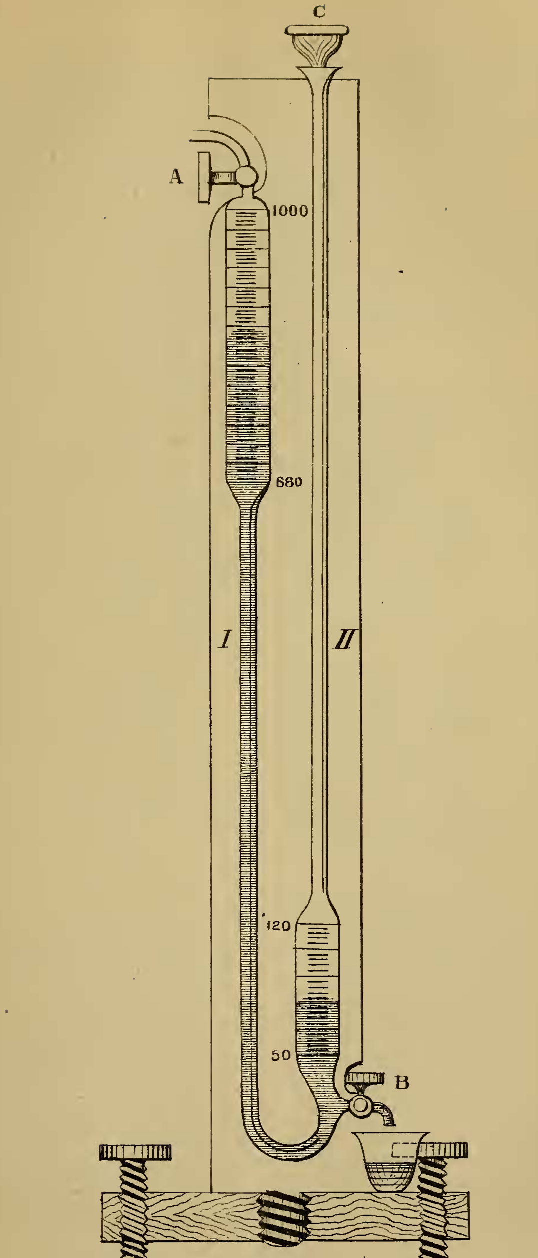
"In the first place, while the boiling out of barometer tubes is an operation not devoid of risk, this risk is still further augmented in the case of the syphon form, and in any case the operation is a tedious one. Further, the mercury in the open arm of the latter suffers the well-known oxidation, besides other kinds of fouling; its meniscus is then no longer identical with that in the closed limb, it changes by degrees into a concavity, the metal clings unequally to the inner wall of the glass tube, which it soon renders dirty. In fine, the compensation for capillarity aimed at in the syphon barometer holds good, even under the most favourable circumstances, for only a very short time.

"But these disadvantages attending the use of the syphon barometer can be avoided in the manner about to be described. An instrument of general application can be made quickly, without boiling the mercury, at small cost, and without the requirement of any special skill.

"A glass tube of about two metres long is bent into the syphon form; the two arms, as shown in the sketch (Fig. 2), are of unequal length; the shorter (I.) bears at the upper extremity an air-tight single-way glass stopcock. The longer arm (II.) is open at top. Near the bend, at bottom, a short branch tube carrying a mercury-tight single-way stopcock is attached (soldered on); the latter opens outwards or can be shut off.

"For economy of mercury the tubes, for a large proportion of their length, can be chosen of rather small diameter, only immediately below the stopcock A for a space of about 320 millimetres the tube must be wider; also for a space of from 70 to 90 millimetres close over the stopcock B, in the longer arm, the tube must be of a diameter identical with that under A. This glass tube is now perfectly cleansed (I find it best to finish with strong alcohol), then it is dried by aspiration of several hectolitres of hot dry air

FIG 2



through it, while the tube itself is supported over a warm stove or other suitable source of heat. The caoutchouc connector leading to the aspirator is attached to the tube over A; on the open end of the long arm a chloride of calcium tube is also attached by an indiarubber joint.

"The mode of filling is the following:—First the tube, very carefully dried, is fastened to a narrow wooden board in the manner shown in the engraving. This board ends below in a screw, which is screwed into a base also of wood, and which is supported by three wooden levelling screws. The board has at its upper end a ring for the purpose of hanging up the instrument.

"Thus mounted, with the stopcock A open and the stopcock B closed, well cleaned dry mercury heated to about 100° C. is poured into the tube through a small funnel with capillary termination, which holds back all dust. The mercury drives before it slowly and gradually the air in arm I., causing it to escape through stopcock A. Finally mercury also passes through the stopcock A and the tube above it. Now A is shut and B opened; the mercury now consequently falls out of the arm II. until its surface in this limb has descended to the point of junction of the branch tube, while in arm I. a column approximating the true barometric column remains suspended. The space thus existing above the mercurial column is not quite air free, although in a highly attenuated condition. The instrument may be made to act as a mercurial air-pump upon the air which adheres to the inner surface of the glass tube and on that drawn in by the warm mercury. For a few minutes, however, the instrument is allowed to remain at rest in the condition just described.

"In the next place the stopcock B is closed, the stopcock A also remaining closed; heated mercury is again poured into the open tube II., filling it completely; the small quantity of air contained in the vacuum chamber is compressed into a very small bubble close under the stopcock; A is then opened, allowing this bubble to escape, and afterwards mercury; after this mercury is again fed in again at C, when a stream of air-free mercury flows through A, sweeping with it mechanically all air attached to the glass inner surfaces; after several grammes have thus flowed out A is closed, B is opened, allowing once more the efflux of the mercury from the latter. The chamber above the mercury column is now